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Policy plan for the use of biomass and biofuels in Greece Part I: Available biomass and methodology

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Abstract

Greece is a country in which biomass can play an important role in achieving the 2010 national target of 20% electricity production from Renewable Energy Sources (RES) Residues from traditional agricultural activities, but also the cultivation of new energy crops, can lead to a high level of availability and utilization of biomass energy products in Greece. In order for biomass to make a substantial contribution to the 2010 national target, set by the EU RES Directive 2001/77, as well as the corresponding 2020 target, to be set by the upcoming RES Framework Directive, a national policy plan for biomass and biofuels has to be formulated. This plan will assess the available biomass quantities and the potential and routes, by which this biomass can be converted to final energy products. The aim of the present paper is to discuss the current situation and prospects of biomass availability and exploitation in Greece and to develop a coherent and reliable methodology, in order to assess the conversion of the country' s biomass potential into useful energy products.

Keywords: Biomass in Greece; Energy crops; Bioethanol; Biodiesel

Contents

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1. Introduction

The constantly increasing prices of the conventional fuels (mainly of petroleum and natural gas) and the scenarios of rising average earth temperature (greenhouse effect), lead the European Union (EU) to the promotion of biomass and biofuels usage for both electricity and heat production, as well as for the substitution of liquid fuels in transport (biodiesel, bioethanol, etc.). Ericsson and Nilsson[1] present the biomass potential in Europe as one of the critical points which have to be considered in the way of the EU to fulfil its aims.

Greece, being a member of the EU, is striving to raise the combined heat and power production from biomass and to substitute a substantial amount of gasoline and diesel with liquid biofuels. However, no overall plan exists so far for the country-wide organization of continuous, uninterrupted supply of biomass to the plants that produce these energy products (liquid and solid biofuels, electrical and thermal energy, etc.).

Energy crops have the potential of resolving many issues related to the supply chains of biomass energy production, while being an attractive alternative to a great number of traditional agricultural cultivations in Greece (wheat, corn, tobacco, cotton, etc.), the cultivation of which may not be aligned with the overall framework of Common Agricultural Policy (CAP).

The energy crops that can substitute the relevant conventional cultivations must ensure that a satisfactory long-term income for the farmers is maintained (at least at a comparable level with the present one), while producing biomass in quantities sufficient for the continuous feeding of the plants which convert biomass into other energy products.

The aim of this paper is to study in an analytical way the short-term (5–10 years) perspective of energy agriculture in Greece and to discuss the cultivation of energy crops in the most appropriate areas of the country.

2. Current situation for RES in Greece

The RES Directive 2001/77/EC for electricity production [2] states that Greece must produce 20.1% of its total electricity consumption in the year 2010 from renewable energy sources (RES), including hydroelectric plants [3].

The most recent forecasts of electricity consumption in Greece for 2010 are near 68×10^9 kWh_e. Therefore, the total electricity production from RES should rise to about 13.7×10^9 kWh_e in 2010, in order to meet the aim of the aforementioned directive. Table 1 shows the required installations of RES plants for achieving the 2010 aim.

Table 1
RES Plants for the achievement of the 2010 aims for Greece

RES technology	Required installed capacity in 2010 (MW_e)	Electricity production in 2010 ($\times 10^9$ kWh_e)	Percentage of each RES source (%)
Wind parks	3372	7.09	10.42
Small hydro plants	364	1.09	1.60
Large hydro plants	3325	4.58	6.74
Biomass	103	0.81	1.19
Geothermal plants	12	0.09	1
Photovoltaic plants	18	0.02	0.03
Total	7193	13.67	20.10

Table 2
Basic scenario for the electricity production from RES in 2010

	Installed capacity in 2006 (MW_e)	Additional licences for new plants (MW_e)	Additional RES plants (in planning) (MW_e)	Additional RES plants in Greece (MW_e)	Estimated sum of installed power from RES in 2010 (MW_e)	Estimated electricity generation from RES in 2010 ($\times 10^9$ kWh_e)	Percentage of each RES in 2010 (%)
Wind parks	622	505	1,240	650	3,017	6.34	9.33
Small hydro	100	62		90	252	0.76	1.11
Big hydro	3,018			307	3,325	4.58	6.74
Biomass	24	22		25	71	0.56	0.82
Geothermal	0			8	8	0.06	0.09
Photovoltaic	1	1		8	10	0.01	0.02
Total	3,765	590	1,240	1,088	6,683	12.31	18.10

Table 3
Estimated electricity production from biomass in the year 2010

Total electricity consumption (2010) (MWh_e)	68,000,000
Percentage of RES in the electricity production (%)	20.10
Total electricity production from RES (2010) (MWh_e)	13,668,000
Installed power capacity from biomass-fired plants (2006) (MW_e)	24
Total aim in 2010 (MW_e)	71
Additional power capacity from biomass that has to be installed (MW_e)	47
Estimated availability of biomass-fired power plants (%)	90
Interconnection losses (%)	7
Total electricity production from biomass (MWh_e)	520,581
Total estimated el. Energy provided to the grid from new plants (MWh_e/year)	344,610
Biomass percentage in the total of RES (2010) (%)	3.81

According to the Greek Ministry of Development, it is estimated that if the foreseen plants are ready on time, the integration of RES in the year 2010 will be as presented in Table 2 (basic scenario).

According to this basic scenario, the Greek Ministry of Development estimates that the electricity production from RES will reach values close to the EU derived goal (12.31×10^9 kWh_e, instead of the aim 13.67×10^9 kWh_e).

2.1. Biomass in Greece

Concerning biomass, the scenario described above shows the need of installing new biomass-fired plants with a total capacity of 50 MW_e till 2010. Table 3 shows the estimated electricity production from biomass in the year 2010.

The main biogas resources, like, for example, the large landfills in Athens and Thessaloniki, or the sewage sludge treatment plant serving the greater Athens area are already exploited. On the other hand, due economies of scale, there is little incentive for utilizing the biogas from landfills near smaller cities. Therefore, the biomass used in the ''new'' biomass plants described above should come, almost exclusively, from the agricultural biomass.

2.2. Liquid biofuels in Greece

The aim of the Directive 2003/30/EC [4] of the European Parliament is to support the use of biofuels and other renewable fuels for the replacement of transport petroleum and gasoline in every EU country, so as to achieve an overall 5.75% substitution by 2010. In terms of technological barriers that may appear in biofuel production, many positive steps have already been taken in Europe [5,6]. Taking into account the fact that the percentage of fuel substitution should be 2% (based on the energy content of petroleum and gasoline) by the end of 2005 and 5.75% by the end of 2010, the relevant future plans for Greece, according to the Ministry of Development, are summarized in Tables 4 and 5 [7].

Biodiesel presents no technical obstacles and it could be supplied without any problems to the present diesel infrastructure. More specifically, it can be mixed with diesel in a volume percentage of up to 5%, according to the norm EN 590:2004. Recently, research projects focus on various engines (pickups, truck engines, etc.) in which tests of mixtures of biodiesel/diesel ranging from 2% to 98% (B2) up to 100% to 0% with the use of some additives are performed [6,8].

On the other hand, bioethanol may cause serious technical problems when mixed with gasoline (e.g. water sensitivity, vapour–pressure increase, etc.). For this reason, it is proposed to transform bioethanol into ethyl tertiary butyl ether (ETBE) and to mix this last product with gasoline [9]. The mixture volume percentage of ETBE with gasoline may be up to 15%, compared to 5% for the (waterless) bioethanol (according to the technical norm EN 228:2004). However, there are currently concerns about the possibility of pollution of ground water arising from the use of ETBE [10].

Greece has enforced Directive 2003/30/EC by passing national law 3423/2005, which enables either the production or import and trading of biofuels.

Up to date, two biodiesel production plants have been constructed:

Table 4
Required biodiesel quantities (in tonnes) for each year according to the EU Directive (2003/30/EC)

Year	Diesel consumption[a]	Required biodiesel percentage[b]	Required biodiesel quantity[c]
2005	2,084,000	2.00	46,976
2006	2,125,000	3.00	71,851
2007	2,167,000	4.00	97,695
2008	2,208,000	4.50	111,986
2009	2,249,000	5.00	126,739
2010	2,290,000	5.75	148,407

[a] Estimated tonnes [7].
[b] According to Directive 2003/30/EC [4].
[c] Taking into consideration that the lower heating value of diesel fuel is 42.74 MJ/kg, whereas of biodiesel is 37.92 MJ/kg.

Table 5
Required bioethanol quantities (in tonnes) for each year according to the EU Directive (2003/30/EC)

Year	Gasoline consumption[a]	Required bioethanol percentage[b]	Required bioethanol quantity[c]
2005	3,707,000	2.00	120,441
2006	3,800,000	3.00	185,195
2007	3,892,000	4.00	252,904
2008	3,984,000	4.50	291,243
2009	4,077,000	5.00	331,157
2010	4,169,000	5.75	389,424

[a] Estimated tonnes [7].
[b] According to Directive 2003/30/EC [4].
[c] Taken into consideration that the lower heating value of gasoline fuel is 43.76 MJ/kg whereas of bioethanol is 26.94 MJ/kg.

- One by the company ELBY S.A. in Kilkis which currently produces 40,000 tonnes/a (with the capacity for doubling production), and with the possibility of using about $900{,}000 \times 10^3\ m^2$ of rapeseed cultivations.
- One by the company ELINOIL S.A. in Volos with a capacity of 40,000 tonnes/a and a total investment cost of €11,000,000.

Four more companies have announced plans for constructing biodiesel plants in Greece, namely:

- Pettas S.A. in Patra with a capacity of 50,000 tonnes/a.
- Greek biofuels S.A. in Magnissia, with the aim to cultivate $1{,}500{,}000 \times 10^3\ m^2$ of rapeseed for supplying a biodiesel plant with a capacity of about 165,000 tonnes/a.
- AGROINVEST S.A. (in Fthiotida), for a plant with a capacity of 240,000 tonnes/a.
- Biodiesel S.A., for a plant producing 100,000 tonnes/a, in an area owned by the Sovel industry complex in Almyro Magnissia.

3. Biomass resources in Greece

In this section, the basic primary biomass types are being categorized. Furthermore, a methodology is proposed for assessing the technically available biomass at local level.

3.1. Categorization of biomass resources and evaluation methodology

3.1.1. Biomass distribution and biomass potential in Greece

Nowadays, the problems for the energetic use of biomass do not concern the various ‘‘technical’’ barriers and difficulties that are linked with them, but the ‘‘non-technical’’ obstacles that constitute a very important part of the legislative background of each EU member state, generally, and also the lack of a clear overall approach for the establishment of policy plans for the energetic use of biomass in countries like Greece.

According to its availability, biomass can be classified in two large categories as seen in Table 6.

Reliable and systematic data collection of the energetic potential of the already available biomass is not carried out in Greece, with the exception of the National Statistical Service of Greece [11], some general studies (Agricultural University of Athens [12], Energy offices, Centre for Renewable Energy Sources [13], etc.) and some targeted estimations that are carried out on behalf of investors, for specific biomass energy projects.

It should be remarked that existing estimations concerning the available biomass potential in Greece present great differences among them. Table 7 lists various estimations of the annual production of biomass in Greece, as presented in the literature.

It must be remarked that most of the data presented in Table 7 are probably inaccurate (especially data concerning categories 1E and 1F). The above described literature data do not take into consideration that in all biomass harvesting methods, there is a high percentage of loss of organic material; probably as high as 20–25% by weight (this is to be considered especially in the case of energy crops).

Furthermore, it has to be mentioned that in the aforementioned studies there is no distinction between the theoretically available biomass and the technically and economically available biomass, which corresponds to the biomass that can be energetically exploited.

Table 6
Biomass classification according to availability

(1)	Actually available biomass, this category is further divided into:
(1a)	Directly available biomass, such as the solid or liquid wastes coming mainly from large agricultural activities (e.g. olive oil activities, cotton ginning, agriculture-cattle breeding), forest industry (e.g. paper industries), as well as municipal solid waste (MSW).
(1b)	Indirectly available biomass, such as the residues from agricultural cultivations (e.g. straw, corn and cotton) and forest activities (non-collected residues from forestry).
(2)	Future-available or ‘‘new’’ biomass, namely energy crops (forest short-term cultivations, like, for example, eucalyptus, acacia types, etc., or non-lignin cultivations like Miscanthus, cane, etc.).

Table 7
Estimation of the annual energy potential of biomass in Greece

Biomass type	Annual production (tonnes)[a]	Availability (%)[b]	Average LHV[c] (MJ/kg)	Energy potential (MJ × 10^6)	Tonnes of oil equivalent[d] (TOE)
(1A) Olive husk [14]	250,000	90	16.5	3,712	88,672
(1B) Cotton ginning residues [15]	60,000	90	15.5	810	19,346
(1C) Forest industry residues [16]	200,000	50	16.5	1,650	39,410
(1D) Organic waste	17,300,952	–	–	320	7550
(1E) Agricultural residues [17]	4,290,773	10	16.0	10,298	245,960
(1F) Forestry residues [18]	1,370,314	10	16.5	2261	54,003

[a] Tonnes on a dry basis.
[b] Economically available percentage (% of the annual production).
[c] LHV, lower heating value.
[d] One tonne of oil equivalent (TOE) = 41,868 MJ.

That creates the need to formulate an exact methodology for calculating the technically and economically exploitable biomass potential.

3.1.2. Proposed methodology for the assessment of the technically and economically exploitable biomass potential at a given geographic area

Even if the analysis is focused in a specific geographic application area in Greece (e.g. in Viotia), the local biomass availability as a primary source for energy production is subject to significant fluctuations due to the weather conditions, the applicable agricultural practices in the area, the level of cultivation subsidies, the current EU and international regulations (e.g. Common Agricultural Policy, World Trade Organization), the competitive uses for local biomass (e.g. for industrial forestry, paper, forage), etc.

Therefore, the estimation of the availability of the appropriate biomass for energy production, on an absolute constant base and under a strictly set composition and physical–chemical characteristics (e.g. fuel analysis, heating value, humidity, ash percentage and composition) is not possible. However, if a well structured and proven methodology is used, it is possible to make a safe, yearly averaged, estimation of the technically and economically available biomass quantities suitable for further energetic use.

A desirable characteristic of the biomass-fired power and CHP plants is the capability to use simultaneously various biomass types. This characteristic increases the techno-economic viability of the plants, strengthening economic and environmental benefits and advantages.

Based on this principle, it is clear (especially in power production plants) that these plants should have a multi-feeding capability, in order to be fed with the biomass which is available during each time period, avoiding dependency on specific feedstocks and suppliers.

However, because of the multi-feeding capability, the plants are due to uncontrolled fluctuation of the fuel input quality. This fluctuation may lead to substantial operating cost increase.

When a wide range of primary biomass feedstocks is used in the plants, successful operation is ensured by the fact that the thermo-chemical processes (combustion, gasification, pyrolysis) that take place in the primary processing equipment of these plants (combustion chamber, gasifier, etc.) are suitable for a wide range of conditions (e.g. high mixing in the fluidized beds or forced movement in the grate for plants with moving grates) and high temperatures (>1000 °C for combustion, 800–1000 °C for the gasification and ≈500 °C for pyrolysis). In these conditions, the fluctuation in the physical–chemical properties of the fuels does not play any significant role (this happens mainly in combustion, which is the most widely applied conversion technology nowadays) and, consequently, the multi-feeding capability of the plant constitutes the main characteristic of their total processing scheme, since there are no significant problems during operation.

Similar is the situation with the plants that produce second generation liquid fluids, since the gasification process that takes place alleviates the problem of physical–chemical differences in the various types of biomass feedstocks.

On the other hand, in the conventional plants which produce first generation biofuels (bioethanol, biodiesel) constant feeding is needed. This is due to the fact that either the conversion processes need careful adjustment of the conditions and, consequently, feeding with biomass of constant characteristics (bioethanol), or the final product must correspond to given standards, in which case, the feeding with specific primary sources is a prerequisite (biodiesel).

Generally, in a first stage, for the viability of a biomass conversion unit, the wide spectrum of primary sources that could be used must be taken into consideration, while in a second stage, the technically available biomass potential in the application area must be validated.

The various categories of primary sources cover all biomass types. More specifically, according to Table 6, they represent:

- The high quality, but difficult to find biomass sub-products (direct biomass), coming from the wood industry (wood chips, etc.) that have high heating value and low ash and humidity content.
- The agricultural wastes (indirect biomass, e.g. cotton residues, or vineyard residues), as well as organic sub-products (greenhouse residues, etc.), with a quite variable composition and high ash (5%) and humidity content (up to 60%).
- The energy crops (new biomass that constitute the next generation of primary sources).

Table 8
Biomass categories and geographic areas for its exploitation

Biomass type	Category	Geographic areas (prefectures) of Greece having high potential of this specific biomass category
A	Olive oil cultivation, processing and relevant products	Lakonia, Messinia, Ilia, Heraklion
B	Grape vine cultivation	Corinth, Crete
C	Tree cultivation (residues)	Imathia, Pella, Argolida
D	Forestry (residues)	Euritania, Rodopi
E	Residues of several cultivations	Viotia, Larissa, Karditsa, Aitoloakarnania, Evros
F	Greenhouse residues	Crete
G	Energy crops	Practically all agricultural regions
H	Organic by-products	Thessaloniki, Trikala, Preveza, Evia, Aitoloakarnania, Chalkida

For practical applications and for carrying out feasibility studies of biomass investment plans, biomass categorization has to be more precise. The specific biomass categories that are interesting for the feeding of biomass-to-energy plants and for biofuels production in Greece are presented in Table 8. In this table, the prefectures of Greece that have significant potential to exploit specific biomass types are presented.

Each biomass category includes partial biomass types for which a detailed analysis concerning its availability is needed. This is done in the fuel study stage and is a prerequisite for every financial plan of energy exploitation of biomass. The availability and the characteristics of every biomass type vary and therefore a different approach is needed. This approach should take into consideration the financial and seasonal aspects, which are linked with the future energy exploitation of this biomass type in the plant.

It is once more underlined that the use of biomass including as many types as possible, ensures the long-term feeding of the power production plants and eliminates the problems that may appear (seasonal lack of a biomass type, price rise, pressures from the local authorities, etc.). On the other hand, in the case of liquid biofuels, it is important to use biomass of one or two types.

3.1.3. Proposed methodology

The proposed methodology for the calculation of the quantity of the economically available biomass for a given application in a certain area, follows three stages that are described in details in this part of the article.

3.1.3.1. Stage A: Identification of the available biomass potential for a specific application in a specific area. This stage consists of the following two stages:

Stage A1: Identification of various categories and biomass types, which could contribute to specific biomass exploitation scenarios, according to their suitability for a given energy conversion plant. As a general principle it can be underlined that:

- All lignin-cellulose types (residues from oil production, forestry residues, woody energy crops) are suitable mainly for:
  - production of solid biomass fuels (pellets and brickets) and
  - power and/or heat production.
- All the plants containing sugar (e.g. beet) or starchy plants (e.g. corn), sweet sorghum are mainly suitable for bioethanol production, whereas sunflower and rapeseed for the production of biodiesel.

The above mentioned are the main directive principles, since in the near future (in about 8–10 years), the production of liquid biofuels (not only bioethanol) will be based on lignin-cellulose biomass (even on the organic part of the Municipal Solid Waste MSW) through thermo-chemical methods (mainly gasification and/or pyrolysis).

Stage A2: Collection and organization of data of primary production for each type of biomass in the application area (usually this corresponds to a prefecture).

For the calculation of the theoretically available biomass potential, it is necessary to have an analysis of the following data:

- Collection of information and data of primary production (here the source of this data has to be carefully examined and could be the National Statistical Service of Greece, Agricultural Authorities of Greece, Agricultural directions in the prefectures, etc.).
- Analysis of the data.
- Development of a simple algorithm for the estimation of the theoretically available quantities, according to the various categories and types of biomass, as well as their energy content.

Based on this data and the analysis of the physical–chemical characteristics of every recognized biomass type (lower heating value, moisture, ash, etc.), some realistic assumptions are realized, concerning the energy content of the theoretically available biomass. Based on these assumptions, some quantitative estimations are resulted (by means of some simple mathematical equations) concerning the really available quantities of each biomass type and their energetic content.

The main result of Stage A is the seasonal distribution of the theoretically available biomass potential in the surface of the under examination area as well as their energy content.

3.1.3.2. Stage B: Calculation based on data from Stage A, after taking into consideration the local limitations and the operation of the supply chain, the technically exploitable potential for the recognized biomass types and the theoretical capacity of the energy conversion plant. This stage consists of the following four stages:

Stage B1: Land-planning examination at the installation area of the biomass energy conversion, e.g. the presence of local networks (electricity network for the electricity production, water network for the cooling or other thermal uses like district heating network, transport ways for the transportation of primary sources, etc.).
Stage B2: Physical restrictions (e.g. % of primary energy loss during the remaining of biomass in the fields) and losses of biomass during the works performed in the supply chain (collection, transport, storage, etc.).
Stage B3: Technological restrictions of conversion, which result during the analysis and selection of the needed processes of biomass pre-treatment in the fields or/and in the conversion units (e.g. need for further drying or chipping, long-term storage, etc.), according to biomass type and category (as these are set in Stage A).
Stage B4: Setting of the theoretical potential of biomass energy conversion units for the given application, based on the technological feeding restrictions and conversion of the recognized primary sources of the given area.

The main output of Stage B is the determination of the theoretically maximum capacity of the given conversion unit in the area of research.

3.1.3.3. Stage C: Calculation, based on data from Stage B and taking into consideration again the local restrictions and the operation in praxis of the supply chain, of the technically and economically exploitable biomass potential and the "realistic" capacity of the given biomass energy conversion unit. This stage consists of the following four stages:

Stage C1: Estimation of the cost of the in situ acquisition, for each one of the recognized biomass types, of the pre-treatment cost (e.g. if chipping is needed) and the transportation cost to the conversion unit. In this estimation, also the amortization of the equipment that is needed for the realization of the works at the supply chain (see Stages B2 and B3) is taken into consideration.
Stage C2: Estimation of the specific investment cost (SIC), according to the applied energy conversion technology for primary biomass (e.g. in €/kW$_e$ for power generation units or co-generation, €/tonnes of pellets or €/tonnes of bioethanol or biodiesel for biofuels production), and the scale of the application (size of the plant).
Stage C3: Estimation of the total operating cost (TOC) of the energy conversion plants (¢€/kWh$_e$ for power generation units, €/tonnes of pellets and €/tonnes of the product for bioethanol and biodiesel units), according to the used technology and the scale of application (size of the plant).
Stage C4: Economic evaluation of the project and examination of the following economic parameters: internal rate of return (IRR), the discounted payback period (DPP) and the net present value (NPV).

From the evaluation of the economic viability of the specific conversion units the need to meet specific assumptions for the supply of biomass types of which the choice would provide an economically viable operation of the conversion units appear. The quantities that correspond to these assumptions will constitute the economically available biomass potential for the given application in the specific region.

The main results of Stage C, which is the final stage of the proposed methodology, are:

(1) The final decision for the capacity of the conversion plants and the exact setting of the mixture of the feeding fuel with biomass.
(2) The fuel cost (more specifically the cost of the partially recognized biomass types) of the plant.
(3) The revenue of the biomass farmers.
(4) The specific investment cost (SIC) of the given conversion plants (units of energy exploitation of primary biomass).
(5) The total operating cost (TOC) of the specific conversion plants (including or non-including the fuel cost).
(6) The economic viability of the conversion plants in these regions.

3.1.4. Energy crops and produced primary sources (present experience, efficiencies and application suitability)

Energy crops are cultivated or self-sown kinds of plants that produce biomass (as main product) which can be further used for various energy aims, like heat production, electrical power, biofuels (solid pellets or liquid biodiesel, bioethanol, etc.) [19]. Energy crops are divided in two main categories: the agricultural energy crops and the forest energy crops. The agricultural energy crops are further divided into annual and perennial crops.

In this section, the main energy crops that could be cultivated in Greece are presented. These energy crops, according to the European Union are the most suitable for southern European countries and especially for Greece. They are divided as follows (according to Table 8):

(1) Forest energy crops (called G1 according to the categorization of Table 8):
  - Two types of Eucalyptus (*Eucalyptus globules* Labill, *Eucalyptus camaldulensis* Dehnh).
  - *Robina pseudoacacia* L.

(2) Agricultural energy crops (called G2 according to the categorization of Table 8):
  - Perennial crops, e.g.
    - *Arundo donax* L.
    - Miscanthus x giganteus GREEF et DEU
    - *Cynara cardunculus* L.
    - Switchgrass (*Panicum virgatum* L.)
  - Annual crops, e.g.

- Sweet and fiber sorghum (*Sorghum bicolor* L.)
- *Hibiscus* L.
- *Brassica napus* L., *Brassica carinata* L. Braun.

Nowadays the contribution of energy crops in biomass energy conversion in Greece is negligible. A recent study of the European Environment Agency (EEA) estimates that ≈365,000 ha in Greece could be cultivated with energy crops. That is the aim for 2010. This estimation is very important, since EEA refers to ''sustainable'' energy crops cultivation, without any environmental effect (e.g. with reduced use of fertilizers, with conservation of forestry, etc.).

3.1.5. Exploitation of already available biomass and energy crops—the case of power production from biomass

In order to realize an efficient operation of power and/or co-generation, it is important to ensure the possibility of co-feeding various fuels. Therefore, the feeding needs of these plants with a primary energy mixture, show a new direction which should be followed by the farmers. In this case, farmers should use their agricultural residues in combination with the development of new biomass (energy crops suitable for feeding of power units).

According to the above statement, farmers should be aware of the organization of primary energy sources supply and the operation of logistics:

- of the primary energy sources that are provided as sub-products or residues of a certain agriculture (e.g. olive cultivation, wine cultivations) based on the management of the already available biomass and
- of the primary sources that are provided as main products of a new agricultural activity such as the energy corps, with emphasis to the management of new biomass.

Therefore, the farmers' activities should be concentrated in two points: in the arrangement of the operation of the supply chain for already available biomass and, on the other hand, in the creation of appropriate conditions for efficient operation of the supply chain for new biomass.

4. Biomass conversion plants in Greece

The availability of primary sources is the main parameter when discussing the feasibility of investments on the energy exploitation of biomass. Some areas in Greece with high agricultural production (rich biomass potential) and relevant infrastructure (agricultural production equipment, know-how and developed transportation net) are the main targets for the realization of such investments.

The conversion technologies discussed in this article are mainly focused on five categories:

(a) Treatment and conversion of biomass to solid fuels (pellets or brickets with a yearly production of 6000 tonnes).
(b) Biodiesel units with an annular capacity of around 40,000 tonnes.
(c) Bioethanol units with an annular capacity of 150,000 tonnes.
(d) Organic waste treatment units with an annular capacity of 50,000 tonnes.
(e) Biomass combustion plants for power production, with an installed capacity of 15 MW_e.

4.1. Targets of the penetration of bioenergy in Greece, quantification and selection of the needed primary sources for the fulfilment of these targets

The main quantitative target, according to the directive 2003/30/EC, is the use of 5.75% of biofuels for transportation in the year 2010. This is interpreted for Greece at the production of ≈150,000 (148,407) tonnes of biodiesel and ≈390,000 (389,424) tonnes of bioethanol a year [7].

Table 9 presents the estimated areas in which supplementary primary sources should be cultivated in order to reach the aforementioned targets. This table is based on the cultivation efficiencies of the already cultivated primary sources (sun-flower for biodiesel and wheat, sugar beet and corn for bioethanol), but also of some appropriate energy crops that have been specified experimentally (rapeseed for biodiesel, sweet sorghum for bioethanol);

Table 9
Efficiencies of the agricultural products for the conversion into liquid biofuels

Biofuel	Primary source	Efficiency of the process (Biofuel yield)				Needed cultivation area ($\times$1000 m^2)	
		($l/1000\ m^2$)[a]		($tonnes/1000\ m^2$)[b]			
		MinY	MaxY	MinX	MaxX	MaxA	MinA
Biodiesel	Sunflower	43	110	0.037	0.095	848,041	494,691
	Rapeseed	43	90	0.038	0.079	824,484	494,691
Bioethanol	Wheat	75	150	0.059	0.119	6,572,564	3,286,282
	Corn	270		0.213		1,825,712	
	Sugar beet	500		0.395		985,855	
	Sweet sorgum	600	900	0.474	0.711	821,570	547,714

[a] Ministry of Development [7].
[b] The losses in the supply chain are not considered.

Table 10
Main primary sources for biomass-fired power plants

Primary sources	Crop yield (dry kg/1000 m^2)		Needed area[a] (×1000 m^2)		LHV (MJ/dry kg)	Supply chain efficiency[b] (%)
	min	max	max	min		
Fiber sorghum	2400	2800	201,633	164,187	17.9	70
Hibiscus cannabinus	1500	2400	329,987	195,930	17.5	70
Cane	800	1250	582,134	353,938	18.6	70
Cynara cardunculus	650	1000	854,257	527,503	15.6	70

[a] Taking into consideration that the "specific" efficiency of fiber sorghum is 1.33 and 1.67 $MWh_e/1000\ m^2$/year, respectively (for minimum and maximum efficiency).
[b] It includes all the supply steps, from the field to the gate of the conversion plant (organic material loss in the field, in the transportation, in the chipping, possible drying, etc.).

Based on the data presented in Table 9, following qualitative conclusions can be remarked:

(1) In the case of biodiesel, the cultivation selection between sunflower and rapeseed is not of great importance, since both are annual plants, the cultivation care of which is well-known.
(2) The efficiencies of sunflower and rapeseed to final product (biodiesel) are similar.
(3) The efficiencies of sweet sorghum to bioethanol are quite high and, in any case, much higher than those of wheat. Furthermore, sweet sorghum contains a woody part, which can be exploited for covering of the high thermal needs of the bioethanol production process. The same is also valid for corn.
(4) The efficiencies of sugar beet are not so low in comparison with sweet sorghum. Taken into consideration that this cultivation is widely known in Greece, this industrial plant can be used as supplementary primary source (together with sweet sorghum) for bioethanol production. In this case, the Greek Sugar Industry must play a significant role, while in its units it is possible to exploit not only sugar beet but also sweet sorghum and corn. It is remarked that this co-treatment is essential due to the possibility of exploitation of the woody part of sweet sorghum and maybe also of corn for the needed heat for distillation of ethanol.

In the case of electricity production from biomass, the efficiencies of primary sources and the most efficient energy crops provided in the experimental phase are taken into consideration (fiber sorghum as annual cultivation and cane as perennial cultivation). Table 10 presents the needed quantities for production of the needed fuels used in electricity generation plants. In this table, the needed cultivation areas are estimated according to the aims of Greece in 2010.

Table 10 shows that fiber sorghum is much more advantageous than the competitive energy crops, mainly in the category of area efficiency.

Regarding the replacement of conventional cultivations with energy crops, following remarks must be taken into consideration:

(a) The most appropriate plants are annual plants, since, in order to achieve an economical cultivation of perennial plants, they have to be productive for at least 15–20 years. Therefore, long-term contracts have to be signed. These contracts must, first of all, fully assure the producers' income and in the same time satisfy the investment profit of the investors. It is, however, expected that farmers will not be in favour of perennial plants, since the costs for the first plantation are very high.
(b) The perennial plants are preferred in the case of "difficult" areas (hilly, without water facility, poor in organic matters, etc.), which are either non-appropriate for the cultivation of annual plants, or are non-suitable for large scale applications (due to the difficulty to apply machinery based cultivation).
(c) The harvesting of *Hibiscus cannabinus*, fiber sorghum and cane is done with the same machines as in the case of corn (sow-thrash machine), when for the *Cynara cardunculus* with the same machines as in the case of grains.

According to the above-mentioned facts and with the aim of replacing the problematic cultivations with energy crops, the realization of conversion units will be based on the following primary sources:

- For bioethanol production, sweet sorghum will be selected, since this plant has been widely studied in the Greek conditions and there is a large quantity of data concerning this plant.
- For biodiesel units, mainly sunflower will be investigated, since this plant is already being cultivated in Greece and has slightly higher final product efficiencies (according to Table 9, if rapeseed was used, no significantly different results would appear).
- For power production units, finally, the case of fiber sorghum will be discussed, since that is a high efficient annual plant.

4.2. Suggested methodology for the installation of bioconversion units

In order to proceed with the planning of bioconversion units in Greece, it is important to investigate the availability of primary sources and more specifically to indicate the areas of the country in which the units can be installed using the appropriate primary sources, converting them into final energy

products. These potential areas should be able to meet the requirements of the units, regarding their yearly capacity (40,000 tonnes of biodiesel and 150,000 tonnes of bioethanol).

Other important parameters that have to be discussed are:

- The cultivation area efficiencies of the primary sources to final energy products, as presented in Tables 9 and 10.
- The percentage of replacement of other (conventional) cultivations with new energy corps.
- The areas in Greece (mostly the agricultural ones), where it would be possible to install technically feasible bioconversion units.

According to this data, several scenarios have been planned in order to include all the parameters. More specifically, the methodology used has taken into consideration:

- The possibility to replace six cultivations (beet, corn, tobacco, hard and soft wheat), which seem to face serious problems by the application of the modified Common Agricultural Policy (CAP) of the European Union.
- The replacement percentage for the specific, under replacement cultivations.
- The geographical distribution of the cultivations that will be replaced. Eighteen agricultural prefectures have been examined (Aitoloakarnania, Fthiotida, Viotia, Ilia, Karditsa, Larissa, Drama, Imathia, Pella, Thessaloniki, Kavala, Kozani, Kilkis, Serres, Florina, Chalkidiki, Rodopi and Evros). In these prefectures, the sum of the areas to be cultivated, for each one of the above-mentioned six cultivations, exceeds the percentage of 75% of the totally cultivated plants of the relevant areas. Therefore, these 18 prefectures are representative for the Greek agriculture.
- Fallow field has been also taken into consideration.

A certain approach has been followed. This approach has structured an analytical methodology. The first stage of this methodology is described as follows:

(1) For the above-mentioned 18 prefectures and the 6 main cultivations to be replaced (beet, corn, tobacco, sweet and hard wheat, cotton), a replacement percentage of the conventional cultivation with new ones has been set (replacement constant). As discussed before, the energy crops that will be planted are: sweet sorghum, sunflower and fiber sorghum. This percentage is varied, according to the cultivation, taking into consideration the directives of the CAP concerning the specific cultivation. This percentage will be the same for all 18 prefectures. The cultivations that are expected to get the highest pressure from CAP are the ‘‘non-nutritious’’ cultivations, namely the industrial cultivations (beet, cotton and tobacco). It is estimated that these cultivations will be replaced with a very high percentage (of around 80%). Furthermore, a very lower percentage of the ‘‘nutritious’’ cultivations (soft and hard wheat, as well as corn) is estimated to be replaced (around 20%), due to the always rising nutritious needs. The replacing percentage of fallow fields is around 50%.

(2) The needed energy crops areas have been calculated according to their average efficiencies (mean value of

Table 11
Cultivated areas of conventional cultivations (data from the National Statistical Service of Greece [11])

	Prefecture	×1000 m^2							
		Beet	Corn	Tobacco	Soft wheat	Hard wheat	Cotton	Fallow field	Olive plantation
1	Aitoloakarnania		141,756	114,112	1,967	66,098	79,833	360,485	278,571
2	Fthiotida	20,323	34,742	42,691	21,630	441,023		143,508	386,882
3	Viotia		17,268	4,035	180	283,345	361,696	33,672	189,169
4	Ilia		175,642		65,818	6,069	29,578	238,553	286,254
5	Messinia		16,659	0	2,900	1,710	0	139,875	712,837
6	Lakonia		5,412	250	4,328	1,942	0	174,835	603,721
7	Karditsa	18,281	62,969	17,751	14,914	185,808	587,611	54,075	
8	Larissa	66,423	76,531	24,123	132,978	780,532	712,447	61,408	60,456
9	Drama	16,244	101,746	4,226	58,860	140,448	101,532	22,815	
10	Imathia	45,476	53,918	21,204	7,473	46,711	156,753	21,635	
11	Pella	21,312	96,851	46,342	18,964	95,247	172,388	8,235	
12	Kilkis	4,307	41,571	20,553	98,306	688,269	94,519	19,140	
13	Thessaloniki	10,300	75,000	23,100	158,000	595,000	178,000	48,585	27,000
14	Kozani	19,465	49,950	15,610	214,549	468,150		28,658	
15	Kavala	16,974	159,973	6,875	22,746	55,800	21,841	15,952	
16	Serres	56,000	150,000	46,240	23,515	549,000	385,664	18,780	53,000
17	Florina	15,582	89,767	1,941	44,939	92,497		18,373	
18	Chalkidiki		3,448	3,829	40,591	401,479	20,681	104,099	
19	Evros	77,876	264,215	3,623	155,948	662,312	177,983	173,947	21,637
20	Rodopi	18,000	15,000	66,500	40,000	290,000	290,000	22,900	
21	Heraklion		47	0	2,960	13,099	0	210,344	879,338
	Total	406,563	1,632,465	463,005	1,131,566	5,864,539	3,370,526	1,919,874	3,498,865
	Total (entire Greece)	441,606	2,067,624	609,174	1,715,463	6,975,841	4,013,435	4,347,396	
	% to entire Greece	92.06	78.95	76.01	65.96	84.07	83.98	44.16	

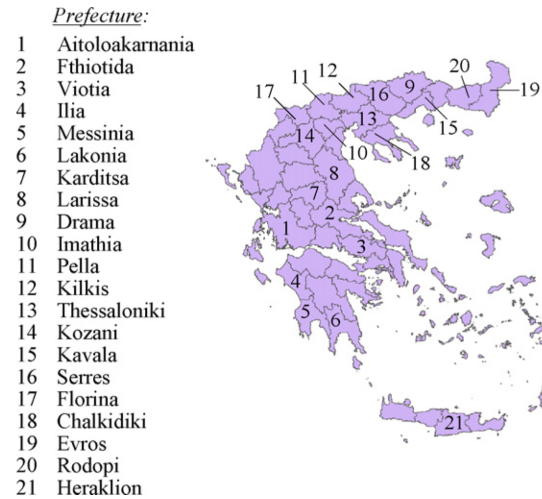

Fig. 1. Map of Greece with the prefectures to be used for the conversion of biomass into final energy products.

minimum and maximum values presented in Tables 9 and 10). Also the final produced energy products have been calculated, after the assumption of the various efficiencies.

(3) The technical availability of the bioconversion units has been examined, based on the least yearly capacity of these units.

Based on the first stage of the proposed methodology, Table 11 presents the cultivation area of the cultivations to be replaced (data taken from the National Statistical Service of Greece [11]), in the 18 prefectures in Greece (+3 olive oil production prefectures). These prefectures are presented on the map of Greece in Fig. 1.

At the second stage of the proposed methodology, the introduction of sweet sorghum in the prefectures that have the richest agricultural production is examined. In these prefectures, it should be possible to install viable bioethanol units with a capacity of around 150,000 tonnes/year each. Taking into account the assumptions for this cultivation and this application, three bioethanol plants of a total capacity of 450,000 tonnes/year can be installed. These three plants will over-cover (15% more) the national aim of 390,000 tonnes/year of bioethanol production for 2010.

At the next stage, the areas that are used for bioethanol production are excluded from the totally available areas for energy crops cultivation. In the rest of the areas, the introduction of sunflower cultivation for biodiesel production is being discussed. If the area of a prefecture is not enough for the feeding of the biodiesel unit (capacity 40,000 tonnes/year), it is possible to use primary sources from neighbouring prefectures.

After investigating the various areas in Greece, it is suggested that five possible biodiesel units can be installed in Greece. These units will have a total capacity of 200,000 tonnes/year and this capacity will exceed (30% more) the national aim for 2010 (150,000 tonnes/year).

Finally, the areas that have been reserved for the production of bioethanol and biodiesel are excluded from the rest of the cultivation fields. The rest of the areas are being examined in order to introduce the cultivation of fiber sorghum for the production of primary sources for power production. This investigation provides, for this specific application, nine possible power generation plants, which have a total installed capacity of $\approx$135 MW_e (=9 $\times$ 15 MW_e).

If some more areas are available for energy crops, it is assumed that they can be exploited for the production of pellets (cultivation of fiber sorghum).

Table 12 is based on the second stage of the methodology and presents:

(a) The areas that can be used for energy crops in the 18 prefectures (+3 olive oil production prefectures).
(b) The areas that will be used for the realization of the above described units.
(c) The areas in which the conversion units will be installed.

4.3. Results from the application of the methodology. Technical feasibility of the bioconversion units

The application of the above described methodology implies a simple way to introduce the cultivation of the primary sources needed for the feeding of the specific plants. The production of these plants, used for both biofuels and electricity, totally covers the aims set from the EU directive for the introduction of bioenergy in Greece till 2010. The results of this methodology and the main assumptions are presented in Table 13.

Concerning the produced liquid biofuels quantities for 2010 and the needed cultivation areas, the results of the methodology for bioethanol and biodiesel production are presented in Tables 14 and 15.

The differences in the calculation of the cultivation area proposed from the Greek ministry of development and the needed area according to the proposed methodology is due to the fact that in this methodology a supply chain efficiency of 70% has been proposed, when in the report of the ministry this efficiency is considered 100% and to the fact that in the proposed methodology, the average value of the efficiencies of the energy crops have been used.

Concerning the power production from biomass, the basic scenario of biomass fuelled plants for 2010 has been presented in Table 3.

According to the already available biomass (mainly residues from olive oil production in the olive oil production prefectures of Greece (Messinia, Lakonia, Ilia and Heraklion)) a quantitative analysis is presented in Table 16.

These residues can be used in other competitive applications and this fact makes them expensive for electricity production. Furthermore, the laws for the olive oil production in the country are not expected to change in the near future.

Therefore, energy crops are expected to play a significant role for the use of great fuel quantities for electricity production. These energy crops will replace other conventional cultivations.

The results of the methodology described, for power production, are presented in Table 17.

Table 12
Area that can be used for energy crops in the 18 Greek prefectures (+3 olive oil production prefectures)

	Prefecture	Area ($\times$1000 m^2)	EtOH (tonnes/ year)	Used for EtOH production ($\times$1000 m^2)	Rest (after EtOH) ($\times$1000 m^2)	Biodiesel (tonnes/ year)	Used for bio-diesel production ($\times$1000 m^2)	Rest (after EtOH + biodiesel) ($\times$1000 m^2)	Used for power production ($\times$1000 m^2)	Free (After EtOH + bio-diesel + power production) ($\times$1000 m^2)	Used for pellets production ($\times$1000 m^2)
1	Aitoloakarnania	377,363	156,511		377,363	35,558		377,363	59,401	317,962	29,562
2	Fthiotida[a]	221,644	91,927		221,644	20,885	54,927	166,717	59,401	107,316	29,562
3	Viotia[b]	369,579	153,283		369,579	34,824	369,579	0		0	
4	Ilia	192,445	79,816		192,445	18,133		192,445	59,401	133,044	29,562
5	Messinia	74,191	30,771		74,191	6991		74,191		74,191	29,562
6	Lakonia	89,954	37,308		89,954	8476		89,954		89,954	29,562
7	Karditsa	578,690	240,012		578,690	54,528	424,507	154,183		154,183	29,562
8	Larissa	871,107	361,291	361,664	509,443	48,003	424,507	84,936		84,936	29,562
9	Drama	169,220	70,184		169,220	15,945		169,220	59,401	109,819	29,562
10	Imathia	211,184	87,589		211,184	19,899		211,184	59,401	151,783	29,562
11	Pella	238,364	98,861		238,364	22,460		238,364	59,401	178,963	29,562
12	Kilkis[b]	270,702	112,274		270,702	25,507	65,494	205,208	59,401	145,807	29,562
13	Thessaloniki[b]	359,013	148,900		359,013	33,829	359,013	0		0	
14	Kozani	188,919	78,354		188,919	17,801		188,919	59,401	129,518	29,562
15	Kavala	92,232	38,253		92,232	8691		92,232	0	92,232	29,562
16	Serres	544,216	225,714	361,664	182,553	17,201		182,553	59,401	123,152	29,562
17	Florina	68,646	28,471		68,646	6468		68,646		68,646	29,562
18	Chalkidiki	160,761	66,676		160,761	15,148		160,761		160,761	29,562
19	Evros[c]	511,054	211,960	361,664	149,390	14,077	44,457	104,934		104,934	29,562
20	Rodopi[c]	380,050	157,626		380,050	35,811	380,050	0		0	
21	Heraklion	108,393	44,956		108,393	10,214		108,393		108,393	29,562
	Total	6,077,726	2,520,737	1,084,991	4,992,735	470,450	2,122,534	2,870,201	534,608	2,335,593	532,123

[a] The neighbouring fields of Viotia and Fthiotida prefectures are used for the installation of a biodiesel plant with a capacity of 40,000 tonnes/year.
[b] The neighbouring fields of Thessaloniki and Kilkis prefectures are used for the installation of a biodiesel plant with a capacity of 40,000 tonnes/year.
[c] The neighbouring fields of Evros and Rodopi prefecture are used for the installation of a biodiesel plant with a capacity of 40,000 tonnes/year.

Table 13
Results of the suggested methodology for the conversion of primary sources into energy products

Bioethanol units (assumptions)	
Energy crop	Sweet sorghum
Supply chain efficiency	70%
Final field efficiency	Average efficiency (see Table 9): 0.404 tonnes EtOH/1000 m^2
Unit size	150,000 tonnes/year
Technically available bioethanol units	
Application area	
Larissa prefecture	One unit of 150,000 tonnes/year
Serres prefecture	One unit of 150,000 tonnes/year
Evros prefecture	One unit of 150,000 tonnes/year
Total (bioethanol)	Three bioethanol units of total capacity 450,000 tonnes/year
Biodiesel units (assumptions)	
Energy crop	Sunflower (rapeseed is also possible)
Supply chain efficiency	70%
Final field efficiency	Average efficiency: 0.0942 tonnes of biodiesel/1000 m^2[a]
Unit size	40,000 tonnes/year
Technically available biodiesel units	
Application area	
Viotia prefecture (together with Fthiotida prefecture)	One unit of ≈40,000 tonnes/year
Karditsa prefecture	One unit of 40,000 tonnes/year
Larissa prefecture	One unit of 40,000 tonnes/year
Thessaloniki prefecture (together with Kilkis prefecture)	One unit of 40,000 tonnes/year
Rodopi prefecture (together with Evros prefecture)	One unit of 40,000 tonnes/year
Total (biodiesel)	Five units of total capacity 192,800 tonnes/year
Power production plant (Assumptions)	
Energy crop	Fiber sorghum
Supply chain efficiency	70%
Final field efficiency	Average efficiency (see Table 10): 2.6 dry tonnes/1000 m^2
Unit size	15 MW_e
Availability of the plant	90% (or 7,884 h/year)
Electrical efficiency of the plant	22% (net)
Technically available units for power production	
Application area	
Aitoloakarnania, Fthiotida, Ilia, Drama, Imathia, Pella, Kilkis, Kozani, Serres	Nine units of installed power 15 MW_e each
Total power production	Nine units of total installed power 135 MW_e

[a] According to Barakos [20], the seeds yields (sunflower or rapeseed) range from 300 to 400 kg/1000 m^2. Based on a seed-to-oil conversion efficiency of 40%, an oil-to-biodiesel process efficiency of 96.15% and a supply chain efficiency of 70%, a specific yield of 0.0942 tonnes/1000 m^2 is derived.

Finally, as presented in Table 12 there is also the possibility of feeding 18 pellets producing units, with a yearly production of 44,000 tonnes of pellets.

A last remark concerning the proposed methodology is that the technical feasibility of the conversion plants (meaning the primary sources availability) and the succeeding installation of the units depend also from other parameters that could play also a significant role for the selection of the appropriate installation area. More specifically:

- Neighbouring ports or railway stations, contribute to the economic transport of primary sources and the final energy products to the markets.

Table 14
Calculation of bioethanol units needed to fulfil the aim of 5.75% in 2010

Primary source for bioethanol production	Sweet sorghum
Number of bioethanol units	3
Bioethanol production (tonnes/year)	450,000
Aim for 2010 (tonnes EtOH/year)	≈390,000
Covering of the national aim (%)	15.38%
Area (×1000 m^2)[a]	702,425
Needed area (×1000 m^2)[b]	1,084,991

[a] According to the aim (Table 5) and the efficiency of sweet sorghum.
[b] Based on the proposed methodology.

Table 15
Calculation of the biodiesel units needed to fulfil the aim of 5,75% in 2010

Primary source for biodiesel production	Sunflower
Number of biodiesel units	5
Biodiesel production (tonnes/year)	≈200,000
Aim for 2010 (tonnes biodiesel/year)	≈150,000
Covering of the national aim (%)	33.33%
Area (×1000 m^2)[a]	2,790,980
Needed area (×1000 m^2)[b]	2,122,534

[a] According to the aim (Table 4) and the efficiency of sunflower.
[b] Based on the proposed methodology.

Table 16
Olive oil production residues in Messinia, Lakonia, Ilia and Heraklion

	Fuels	Messinia	Lakonia	Ilia	Heraklion
A1	Olive husk (from three-phase olive mills)	10,455	10,063	11,871	35,106
A2	Liquid effluents from three-phase olive mills	8,978	8,641	10,195	30,147
A3	Olive tree prunings (branches)	40	39	46	136
A4	Leaves and twigs (collected in the olive mills)	2,305	2,218	2,617	7,739
A5	Exhausted watery olive husk-EWOH (from two-phase mills)	0	0	0	0
A6	Olive pit or kernel (from secondary processing of olive husk)	1,834	1,766	2,083	6,160
A7	Olive pit/kernel (from secondary processing of EWOH)	0	0	0	0
	Total	23,613	22,727	26,812	79,288

Table 17
Calculation of power production plants in 18 main prefectures in Greece using energy crops

Primary source	Fiber sorghum
Number of plants	9
Installed capacity (MWe)	135
Aim of the year 2010 (MWh_e/year)[a]	≈345,000
Estimated production (MWh_e/year)[b]	≈990,000
Covering of the aim (%)	182
Needed cultivation area[c]	534,608

[a] See Table 3.
[b] Electrical efficiency 22% and availability 90%.
[c] According to the methodology and Table 13.

- Neighbouring refineries (in the case of bioethanol) or relevant agricultural industries (e.g. seed-oil industry) can play a significant positive role to the installations.
- The parallel use of other primary sources (energy crops or industrial plants, e.g. beets and corn).
- The collaboration with the Greek Sugar Industry in the case of bioethanol.
- The waste heat from the power plants could be used for the huge thermal needs of bioethanol units. Therefore, a combination of these two types of units could lead to more economic ones.
- The present and future subsidy system for the biofuels could be vital for these investments.

5. Conclusions

As discussed in this paper, the base of every investment plant for energy exploitation of biomass is to ensure the feeding of the units with the needed primary sources.

Therefore, a presentation of the available primary sources has been done, together with the technical calculation of the installation of certain conversion units in specific geographic areas of Greece.

The aim was to describe a methodology that can be applied in Greece in order to introduce the conversion of biomass into energy products, reaching the aims of the country for 2010 which are in accordance with the EU directives.

Following conclusions are remarked:

- The solid biofuel (pellets-brickets) production units can be practically installed in all areas of Greece, since these units are relatively small (≈6000 tonnes of pellets/year) and the final products can be easily introduced at the heat market. The primary sources that can be used are either biomass residues or energy crops.
- Three bioethanol units can be installed in specific areas of Greece. Each of them will have a year capacity of ≈150,000 tonnes EtOH. These units will over-cover the EU directive of replacing 5.75% of gasoline with biofuels.
- The biodiesel units will have a capacity of 30,000–40,000 tonnes of biodiesel a year. Five biodiesel units can be installed over-covering the targets of Greece for 2010.
- The power production (or combined heat and power production) from biomass will be based on the combustion technology. In nine prefectures of Greece, 15 MW units can be installed. The power production plants can be installed near other industries which could take profit of the waste heat of the plants making the investment even more economical. Energy crops or biomass residues can be used in such plants.
- The technical availability of primary sources does not seem to lead to any problem, as long as conventional cultivations are replaced with novel energy crops.

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References

[1] Ericsson K, Nilsson LJ. Assessment of the potential biomass supply in Europe using a resource focused approach. Biomass Bioenergy 2006;30:1–15.
[2] Journal of the European Union. (OJ L283/27.10.2001) Electricity production from RES. Directive 2001/77/EC of the European Parliament and the Council on the promotion of the electricity produced from renewable energy sources in the international electricity market. Brussels; 2001.
[3] Greek Ministry of Development. Third report for the level of introduction of renewable energy sources till the year 2010. Athens; 2005.
[4] Journal of the European Union. Directive 2003/30/EC on the promotion of biofuels. Brussels; 2003.
[5] Faaij APC. Bio-energy in Europe: changing technology choices. Energy Policy 2006;34(3):322–42.

[6] Kahraman B. Biodiesel as an alternative motor fuel: production and policies in the European Union. Renew Sustain Energy Rev 2005.
[7] Greek Ministry of Development. First national report regarding promotion of the use of biofuels or other renewable fuels for transport in Greece for the period 2005 to 2010. Athens; 2004.
[8] Hofman V. Biodiesel fuel. Fargo, North Dakota: NDSU Extension Service, North Dakota State University of Agriculture, Applied Science and US Department of Agriculture cooperating; 2003.
[9] Hammond GP, Kallu S, Mc Manus MC. Development of biofuels for the UK automotive market. Appl Energ 2008;85(6):506–15.
[10] Puppán D. Environmental evaluation of biofuels. Periodica Polytech Ser Soc Man Sci 2002;10(1):95–116.
[11] General Secretariat of National Statistical Service of Greece. http://www.statistics.gr/.
[12] Agricultural University of Athens. http://www.aua.gr/.
[13] Center for Renewable Energy Sources. http://www.cres.gr/.
[14] Souter Ch, Zafiris Ch. Data from the study Thermie: promotion of RES in Greece—Issue 5: Biomass. Athens: Center for Renewable Energy Sources (CRES); 1995.
[15] Papavasileiou D, Choudalis P. Replacing of oil with cotton production residues (Study). Athens: Center for Renewable Energy Sources (CRES); 1993.
[16] Peteinarakis I. Report of GEOTEE (Geotechnical Chamber of Greece). Athens; 2001. p. 45–54.
[17] Zafiris. Data from the report: agricultural-cattle breeding residues. Athens; 2001.
[18] Kyritsis S, Souter Ch, Apostolakis Ch. The energy potential of biomass. Greece: ELKEPA; 1987.
[19] Rowe RL, et al. Identifying potential environmental impacts of large-scale deployment of dedicated bioenergy crops in the UK. Renew Sustain Energy Rev 2007. doi:10.1016/j.rser.2007.07.008.
[20] Barakos N. Contribution of biofuels production from Greek-based feedstocks to agricultural development. Presentation of research activities. National Technical University of Athens, Department of Chemical Engineering. Athens; 2005.